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A COMPARISON OF INFORMATION FUNCTIONS OF MULTIPLE-CHOICE AND FREE-RESPONSE VOCABULARY ITEMS

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and
David J. Weiss

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Twenty multiple-choice vocabulary items and 20 free-response vocabulary items were administered to 660 college students. The free-response items consisted of the stem words of the multiple-choice items. Testees were asked to respond to the free-response items with synonyms. A computer algorithm was developed to transform the numerous free-responses entered by the testees into a manageable number of categories. The multiple-choice and the free-response items were then calibrated according to Bock's polychotomous logistic model.
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One item was discarded because of extremely poor fit with the model, and test information functions were determined from the other 19 items. Higher levels of information were obtained from the free-response items over most of the range of abilities between θ=-3.0 to θ=+3.0.

theta = -3.0 to
theta = +3.0.

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CONTENTS

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A Comparison of Information Functions of Multiple-Choice And Free-Response Vocabulary Items

The multiple-choice item format used by most group tests of mental ability allows testees to obtain correct answers by guessing when they do not know the correct answer. This adds error variance to test scores or, in terms of modern test theory (see Lord & Novick, 1968, chaps. 16-20), decreases the amount of information that the item provides about ability levels.

Several attempts have been made to eliminate guessing by making its effects less attractive: Formula scoring (*i.e.*, correction for guessing) subtracts points for items answered incorrectly, making the expected gain from guessing negligible; confidence weighting and probabilistic responding strategies typically use Reproducing Scoring Systems (Shuford, Albert, & Massengill, 1966) which cause testees' subjective test scores (*i.e.*, the score they think they will get) to be maximized when they answer honestly. Another scoring technique attempts to eliminate the effects of guessing by simply not scoring those items on which a testee is likely to guess (Waller, 1974). These approaches and others have been reviewed by Bejar (1975).

The research reported here was an attempt to eliminate the effects of guessing by making it virtually impossible to obtain a correct answer to a question solely by guessing. This was done by administering items in a free-response format in which testees were required to generate their own response instead of choosing from several alternatives that are provided. To be practical as a group testing approach (*i.e.*, as an alternative to multiple-choice items), these items had to be administered and scored by a computer.

The question of interest guiding this research was, therefore: Will the information gained due to the elimination of guessing using the free-response format be greater than the information lost due to inefficiencies in the machine-scoring algorithm? Inefficiencies refer to things such as a higher probability of errors in responses (*e.g.*, typing errors) due to the more complex format, and the need to group responses into categories because they are too numerous to handle individually.

The answer to this question is obviously dependent on the domain of ability being tested. There is practically no inefficiency in the scoring of free-response numerical items; thus, these items do not provide an interesting area of study. Vocabulary items, in which the responses are English words, provide a more interesting area of study because information will be lost due to misspelling, categorization, etc. The objective of this study was, therefore, to determine if a machine-scoring algorithm could be implemented to extract more information out of free-response vocabulary items than was obtained from those administered in a multiple-choice format.

Method

Purpose

This study involved a comparison of vocabulary test items administered in a free-response format with similar vocabulary items administered in a multiple-choice format in terms of the amount of information each provided regarding a testee's level of ability. Toward that end, 20 five-alternative multiple-choice items were randomly sampled from a 36-item conventional test with rectangularly distributed item difficulties used as part of another study. These items were obtained from Educational Testing Service and had been used in their SCAT and STEP tests; the items had thus been carefully analyzed and were good multiple-choice items. The stem words from these items provided the stems for 20 free-response items. In the free-response items, testees were asked to respond with a synonym rather than indicating their choice of multiple-choice alternative.

Testees

In order to provide data from which to calibrate these items and thus determine their information functions, testees were recruited from two sections of an introductory psychology class at the University of Minnesota consisting primarily of sophomores from the College of Liberal Arts. Test items were presented to testees via cathode ray terminals (CRTs) interfaced to a Hewlett-Packard 9600E real-time minicomputer system. Items were displayed at a rate of 960 characters per second (almost instantaneously) beginning, typically, less than a second after the testee's response to the previous item. Testees could skip items by typing in a "?" as their response if they did not know the answer and chose not to guess.

Tests

Both the 20-item free-response test and the 20-item multiple-choice test were administered to all students. In all cases, the free-response test was administered first (following other multiple-choice items which were independent of those used in this study) followed immediately by the multiple-choice test imbedded in the 36-item test. The multiple-choice test was administered second to avoid providing the testees with alternatives to use in the free-response test (since all the free-response items were present as stems in the multiple-choice test).

At the beginning of the free-response test, each testee was given the following instructions on the CRT:

> *Now you are going to be given some vocabulary test questions which are different from those you've answered so far. These questions will not require you to choose the correct response from a set of alternatives. Instead, you are to type in a one-word response. The computer will present a word or phrase and you are to respond by typing, on the keyboard, the single word that is most alike in meaning to that word or phrase.*
>
> *For example, the computer might present the word "wealthy", followed by a question mark. If you thought the word most similar to "wealthy" was "rich", you would respond by typing the word "rich" after the question mark.*
>
> *When the word "wealthy" appears, type in the word "rich" after the question mark to show that you understand the instructions. If you do not understand the instructions, type in a question mark. Remember that you must always press the return key when you have finished typing in your response.*

WEALTHY

?

If testees failed to enter the word "rich", they were given instructions to call the proctor for assistance. Otherwise, the following message was presented:

Now you are ready to take this part of the test. If you do not know the answer to a question, type in a question mark to skip that question.

Type in "Go" to start the test.

At the end of the free-response test, the following transition back to more multiple-choice items was made:

Thank you. That was the last question of that type. Now, for the last part of today's test we are going to give you some more multiple-choice vocabulary questions. Some of these questions will contain the same words you encountered in the section you just finished. These questions are being repeated so that we can compare how well you do when we don't provide the alternatives. When answering these questions, choose the best alternative from the five available even if none of these alternatives seem as good as your own response.

Type in "Go" to start this section of the test.

Following the 36-item multiple-choice test, other testing continued.

Analysis of Free Responses

Data were collected from 660 testees. More than 60 formally different responses (*i.e.*, words that were not exactly the same) were obtained for each of the 20 free-response stems. Due to computer-program limitations, these raw responses were reduced to the 60 most frequent responses. To complete the analysis, this number had to be further reduced--immediately to nine categories and ultimately to six (again because of program limitations).

The many different responses generated by the testees consisted of four distinct types: 1) frequent responses, both correct and incorrect; 2) misspellings of the frequently used words; 3) variations on the roots of these words (*e.g.*, "loyal" and "loyalty"); and 4) infrequent responses not included in Type 2 or 3. To reduce the number of categories, all responses were first ranked in order of their frequency. Then the most frequent response and other formally similar responses (*i.e.*, composed of a similar string of letters) were grouped into a category, using a formal similarity detection technique based on Alberga's (1967) "algorithm 25" with the recommended threshhold of .12. This algorithm and threshhold proved best, out of a field of 65 in a simulation by Alberga, for recognizing misspellings of target words. Visual inspection of the present data suggested that this technique did indeed recognize misspelled words. In this study, the technique was used to detect both misspellings and variations of roots. The Fortran IV subroutine used is included in Appendix A.

Response clustering continued until eight formally similar clusters (usually including one "omit" category) had been identified. A final "other" category, containing all other responses, completed the nine categories manageable by the programs used at this point in the analysis.

These nine categories were then clustered on the basis of judged semantic similarity in an attempt to have at least 30 responses in each category (a number arbitrarily chosen as a minimum for acceptable calibration of the category). Words that were semantically very similar were clustered; infrequently used and definitely incorrect words, when present, were clustered with the "omit" category; infrequent responses not semantically similar to any of the other categories and not completely incorrect were clustered with the "other" category. The nine initial categories and their ultimate classifications are presented in Appendix Table B-1.

An attempt was made to semantically cluster the alternatives of the multiple-choice items, but no semantic similarity was found. Alternatives were thus either allowed to stand alone if their frequency of endorsement was high enough or were grouped into an "other" category if it was not. The multiple-choice alternatives and their ultimate classifications are presented in Appendix Table B-2.

Item Calibration

The item responses thus categorized were then calibrated according to Bock's (1972) polychotomous logistic model using the program LOGOG (Kolakowski & Bock, 1973). Bock's program yields two parameters, a and c, for each response category of each test item. It should be noted that the a and c parameters have different interpretations than the a and c parameters usually calculated in item characteristic curve theory (*e.g.*, Lord & Novick, 1968).

Let i and j index the I=J categories of a given item. The probability (P_j) of a testee endorsing category j as a function of ability (θ) is:

$$P_j = e^{z_j} / \sum_{i=1}^{I} e^{z_i} \qquad [1]$$

where

$$z_i = c_i + a_i\theta \qquad [2]$$

and a_i and c_i represent the parameters corresponding to category i of the item.

The parameters a_i and c_i, and the function e^{z_i} might be psychologically interpreted as follows: e^{z_i} can be thought of as the attractiveness of response alternative (or category) i of the item as perceived by the testee. As e^{z_i} gets larger, category i becomes more attractive to the testee. But in deciding which alternative to endorse, the testee must also consider the attractiveness of the other response alternatives for that item. Thus, according to the model, the testee's probability of endorsing a category (Equation 1) is equal to the attractiveness of a given category divided by the sum of the attractiveness of all the categories. The function, e^{z_i}, is a monotonic increasing function of z_i, and z_i is either a monotonic increasing or monotonic decreasing function of ability (θ) depending on the sign of the parameter a_i (Equation 2). As a_i increases in absolute value, a given change in ability is associated with a larger change in attractiveness. Thus, a_i may be thought of as an index of category discriminating power. If a_i is positive, attractiveness increases with increasing ability. c_i can be interpreted as an attractiveness-biasing parameter. As a category's c parameter increases, the attractiveness of the category gets larger at all levels of ability. When θ=0, the attractiveness of the categories is ranked in order of their c parameters.

Calculation of Information

Using the category parameters obtained from the item calibration, item information was calculated from Samejima's (1969, chap. 6) general equations. The first and second derivatives of the probability function are given by:

$$P_j' = \partial P_j/\partial\theta = [e^{z_j} \cdot \sum_{i=1}^{I} e^{z_i}(a_j-a_i)] \;/\; (\sum_{i=1}^{I} e^{z_i})^2 \qquad [3]$$

and

$$P_j'' = \partial^2 P_j/\partial\theta^2 = e^{z_j}[(\sum_{i=1}^{I} e^{z_i})(\sum_{i=1}^{I} e^{z_i}(a_j^2-a_i^2)) - 2(\sum_{i=1}^{I} e^{z_i}(a_j-a_i)) \cdot (\sum_{i=1}^{I} e^{z_i}a_i)]/(\sum_{i=1}^{I} e^{z_i})^3 \qquad [4]$$

The information provided about ability by an item as a function of ability $I(\theta)$ is then given by Equation 5 where:

$$I(\theta) = \sum_{j=1}^{J} (P_j'^2/P_j - P_j'') \qquad [5]$$

Item information values were calculated from Equation 5 for each multiple-choice item and each free-response item at 25 points along the ability continuum between θ=-3 to θ=+3. For each response format at each of the 25 ability levels, information values for each of the items were added together to yield a test information value, and a smoothed curve was passed through these values to yield the two test information functions.

Results

Item Parameters

The item parameters, a and c, along with chi-square goodness-of-fit statistics are shown in Table 1 (free-response) and Table 2 (multiple-choice). Free-

Table 1
Parameters and Tests of Fit of Free-Response Items

Item	a	c	χ^2	df	p
1	.733	.329	47.02	40	.21
	-.396	-.710			
	.268	.298			
	-.278	-.184			
	-.364	-.278			
	.037	.546			
2	.795	1.048	49.54	40	.15
	-1.135	-1.023			
	.568	-.252			
	.077	-.280			
	.050	-.357			
	-.355	.864			
3	.347	1.685	19.78	24	.71
	-.813	-1.302			
	.398	-.737			
	.068	.353			
4	.690	.678	31.33	24	.15
	.228	-.088			
	-.611	-.558			
	-.307	-.032			
5	.514	1.730	29.86	40	.88
	-1.675	-2.339			
	.219	.251			
	.465	.223			
	.181	-.475			
	.296	.608			
6	.483	-.651	23.40	32	.86
	-.544	.104			
	.160	.398			
	.371	-.762			
	-.469	.911			
7	.314	.904	21.10	32	.93
	-1.165	-.477			
	.557	-.264			
	.190	-.314			
	.103	.150			
8	1.086	1.489	20.96	16	.18
	-.946	-.723			
	-.140	-.767			
9	1.501	1.397	13.11	16	.67
	-1.438	-1.133			
	-.064	-.264			
10	.299	.304	25.18	32	.80
	-1.476	-.804			
	.350	-.063			
	.857	.066			
	-.030	.497			

Item	a	c	χ^2	df	p
11	1.025	.782	73.91	24	<.01
	-1.503	-2.085			
	.518	1.243			
	-.440	.060			
12	1.098	.189	27.76	24	.27
	-1.501	.728			
	.497	-.654			
	-.094	-.263			
13	.917	-.205	37.82	32	.23
	-1.098	-.883			
	.552	-.510			
	-.240	.640			
	-.133	.958			
14	1.140	-.326	41.03	32	.14
	-1.050	-.256			
	-.912	-.699			
	.654	.125			
	.168	1.157			
15	1.016	-.126	32.30	24	.12
	-.987	.903			
	-.112	-.615			
	.083	-.162			
16	.845	-.462	47.45	40	.20
	-1.188	-1.072			
	.615	.677			
	.144	.398			
	-.273	.021			
	-.142	.439			
17	-.006	-.153	35.98	32	.29
	.045	-.541			
	.586	.757			
	-.740	-.772			
	.115	.709			
18	1.047	-1.261	28.99	24	.22
	-1.360	1.576			
	.737	-1.200			
	-.425	.886			
19	.785	1.365	51.68	32	.02
	-2.197	-3.252			
	.434	1.143			
	.260	.223			
	.718	.521			
20	.736	-1.210	22.19	24	.57
	-.442	1.754			
	-.423	-.676			
	.128	.132			

Table 2
Parameters and Tests of Fit for Multiple-Choice Items

Item	a	c	χ^2	df	p	Item	a	c	χ^2	df	p
1	.140	1.225	10.75	8	.22	13	.969	1.888	28.78	32	.63
	-.140	-1.225					.282	-.209			
2	.839	2.528	5.41	8	.71		-.113	-.173			
	-.839	-2.528					-.263	-.469			
3	1.100	2.133	2.50	8	.96		-.875	-1.037			
	-1.100	-2.133				14	.957	1.863	26.31	32	.75
4	.792	1.387	13.00	8	.11		.013	-.183			
	-.792	-1.387					-.010	-.096			
5	.819	1.606	3.82	8	.87		.067	.194			
	-.819	-1.606					-1.028	-1.778			
6	.700	2.083	19.73	16	.23	15	.753	1.560	43.14	32	.09
	-.280	-1.831					.003	.147			
	-.419	-.252					.010	-.773			
7	.719	1.762	17.48	16	.36		-.208	-.936			
	-.094	-.770					-.559	.002			
	-.626	-.993				16	.714	1.329	19.99	16	.22
8	1.416	2.579	12.28	24	.98		-.124	.111			
	-.501	-.821					-.590	-1.441			
	-.437	-.521				17	.580	.587	29.19	16	.02
	-.478	-1.238					-.392	-.282			
9	1.346	2.376	4.25	16	>.99		-.187	-.305			
	-.669	-.653				18	15.440	12.777	*____	32	<.01
	-.677	-1.722					-1.739	9.512			
10	.952	1.827	7.93	16	.95		-.067	9.589			
	-.443	-1.145					-15.685	16.010			
	-.510	-.682					2.051	-47.887			
11	1.362	2.126	15.27	24	.91	19	.761	-.154	47.71	16	<.01
	-.626	-.859					-.224	1.260			
	-.075	-.353					-.537	-1.107			
	-.661	-.914				20	.584	.186	89.60	40	<.01
12	1.530	1.602	47.07	32	.05		.930	.158			
	-.271	-.749					-.199	-.334			
	.094	.543					-.617	-.991			
	-.813	-1.118					-.332	.447			
	-.540	-.276					-.367	.554			

* Value overflowed program format; $\chi^2 \geq 10^6$

response items 11 and 19 (Table 1) showed lack of fit with the logistic model significant at $p<.05$, but the other items exhibited no significant lack of fit. Multiple-choice items 12, 17, 18, 19, and 20 (Table 2) showed significant lack of fit with the model. This lack of fit is probably an effect of guessing, which Bock's model assumes does not occur. Although testees were given the opportunity to omit items, it is likely that some guessed anyway; items 17 through 20 were the most difficult items and thus most likely to elicit guessing behavior. Item 18 showed profound lack of fit and had extremely unrealistic item parameters in the multiple-choice format. It was therefore excluded from further analyses in both the multiple-choice and free-response formats.

Information

Smoothed test information functions for both the multiple-choice and free-response tests are shown in Figure 1. Test information values for both tests are included in Appendix Table B-3.

Figure 1
Test Information Functions for Two 19-Item Tests

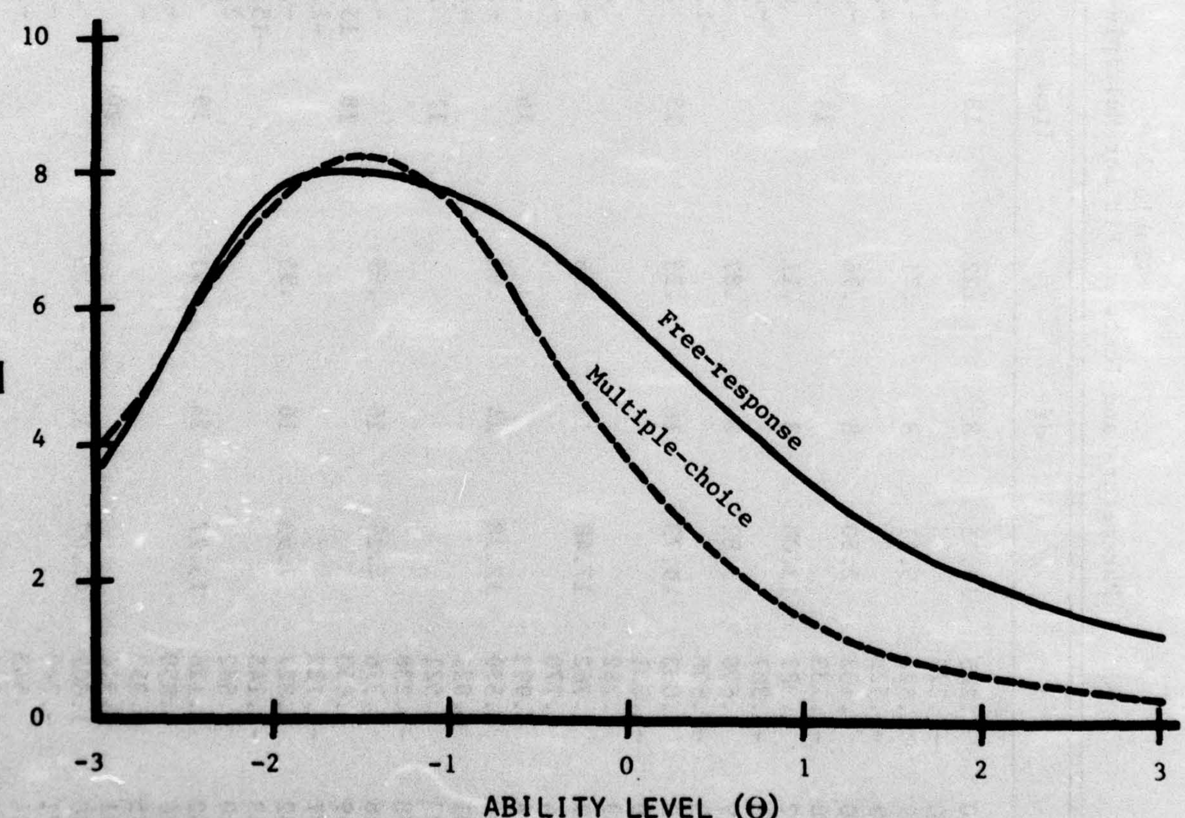

Figure 1 shows that both tests were too easy for the population to which they were applied in this study because they provided maximal information at about $\theta=1.5$; assuming θ distributed normally with a mean of zero and a standard deviation of 1.0, the test information function should have peaked at $\theta=0$ to provide the highest reliability coefficient.

But more importantly, Figure 1 shows that while items administered in the two response formats provided equivalent amounts of information near ability levels where the information function peaked, the free-response items yielded more information at the higher ability levels. Simply removing the effects of guessing should result in increased information at low-ability levels rather than at high ones because the effects of guessing are greater at low-ability levels (see Figure 20.4.2 in Lord & Novick, 1968). But the free-response format involves a recall task (rather than a recognition task as in the multiple-choice test format), and this probably made the items more difficult, thus shifting the information function to the right.

These information functions should be viewed further in light of the ease of construction of the two types of items. The multiple-choice items were undoubtedly written by professional item writers at ETS, selected for their ability to discriminate ability levels, and were designed with well-functioning distractors. Beyond selection of the stems (which, in this study, were fixed by the multiple-choice items), the 20 free-response items required only a few minutes of computer time to score and about one hour to develop. With further research, designed to develop guidelines for selection of good stems, good free-response vocabulary items would be much easier to produce than are multiple-choice items.

Conclusions

This study has shown that vocabulary items presented in a free-response format can provide more information than similar items presented in a multiple-choice format. There are two probable sources of this superiority. First, obtaining a correct answer by guessing is not possible using the free-response format, and information lost, due to the uncertainty about whether testees answered correctly because they knew the answer or because they guessed, is recovered. Secondly, more latitude in degree of correctness is present in free-response items than is typically present in multiple-choice items and a testee's degree of partial knowledge is easier to assess. These advantages apparently overshadowed any deficiencies present in the machine-scoring algorithm used in this study.

This research was designed as a demonstration that the free-response format scored by a computer is more informative than the multiple-choice format. It was not a far-reaching comparison with all other potential response formats. Future research should compare free-response items with other formats such as a confidence-weighting format or a probabilistic format. It should also compare them with multiple-choice items having more alternatives and/or wrong alternatives graded in difficulty rather than all completely incorrect. (Although scored as if they were gradable in this study, the alternatives of the items used were not designed to be graded in difficulty.) Future research should also investigate the effects of various techniques of semantic clustering and detection of formal similarity. The techniques used in this study were probably not optimal for extracting maximal information from the free-response items (*i.e.*, the clustering and similarity detection were clinical in nature and were not explicitly designed to extract maximum information from the items), and better techniques should produce results even more favorable to the free-response format.

REFERENCES

Alberga, C. N. String similarity and misspellings. Communications of the ACM, 1967, 10, 302-313.

Bejar, I. I. An investigation of the dichotomous, graded and continuous response level latent trait models. Unpublished doctoral dissertation, University of Minnesota, 1975.

Bock, R. D. Estimating item parameters and latent ability when responses are scored in two or more nominal categories. Psychometrika, 1972, 37, 29-51.

Kolakowski, D., & Bock, R. D. LOGOG: Maximum likelihood item analysis and test scoring--logistic model for multiple item responses. Chicago: National Educational Resources, 1973.

Lord, F. M., & Novick, M. R. Statistical theories of mental test scores. Reading, MA: Addison-Wesley, 1968.

Samejima, F. Estimation of latent ability using a response pattern of graded scores. Psychometrika, Monograph Supplement No. 17, 1969.

Shuford, E. N., Albert, A., & Massengill, A. E. Admissible probability measurement procedures. Psychometrika, 1966, 31, 125-145.

Waller, M. I. Removing the effects of random guessing from latent trait ability estimates. (Research Bulletin 74-32). Princeton, NJ: Educational Testing Service, 1974.

APPENDIX A

A Fortran Subroutine for Assessing the Formal Similarity of Two Words (from Alberga, 1967)

```
      SUBROUTINE MATCH (ITARG,ITEST,NTARG,NT,SIMVAL)
      DIMENSION ITARG(NTARG),ITEST(NT),COIN(20,20),ICOL(20)
C     ROUTINE DETERMINES SIMILARITY BETWEEN TWO WORDS
C     ACCORDING TO ALGORITHM 25 REPORTED IN ALBERGA, 1967,
C     COMMUNICATIONS OF ACM.
C     PARAMETERS :
C          ITARG  = ARRAY CONTAINING TARGET WORD - ONE CHARACTER PER
C                   COMPUTER WORD, RIGHT JUSTIFIED, ZERO FILLED
C          ITEST  = ARRAY CONTAINING TEST WORD
C          NTARG  = NUMBER OF CHARACTERS IN TARGET WORD
C          NT     = NUMBER OF CHARACTERS IN TEST WORD
C          SIMVAL = RETURNED SIMILARITY VALUE
C
10    DO 20 I=1,20
      ICOL(I)=0
      DO 20 J=1,20
      COIN(I,J)=0.0
20    CONTINUE
      C=NTARG
      T=NT
C     FILL COINCIDENCE MATRIX WITH ROOF WEIGHTS
100   DO 110 I=1,NTARG
      DO 110 J=1,NT
      IF (ITARG(I) .NE. ITEST(J)) GO TO 110
      DIST=ABS(FLOAT(I-1)/(C-1.0)-FLOAT(J-1)/(T-1.0))
      COIN(I,J)=1.0-DIST
110   CONTINUE
C     SELECT ELEMENTS ACCORDING TO SLYC ALGORITHM
200   DO 230 I=1,NTARG
      TEST=-1.0
      LOC=0
      DO 210 J=1,NT
      IF (COIN(I,J) .LT. TEST .OR. ICOL(J) .EQ. 1) GO TO 210
      TEST=COIN(I,J)
      LOC=J
210   CONTINUE
      IF (LOC .GT. 0) ICOL(LOC)=1
      DO 220 J=1,NT
      IF (J .EQ. LOC) GO TO 220
      COIN(I,J)=0.0
220   CONTINUE
230   CONTINUE
C     SUM ACCORDING TO STRING ALGORITHM
      SUM=0.0
      J=1
300   PREV=0.0
      IF (J .GT. NT) GO TO 400
      DO 310 I=1,NTARG
      IF (COIN(I,J) .GT. 0.0) GO TO 320
310   CONTINUE
      J=J+1
      GO TO 300
320   PREV=PREV+COIN(I,J)
      SUM=SUM+PREV
      J=J+1
      I=I+1
      IF (I .GT. NTARG .OR. J .GT. NT .OR. COIN(I,J) .LE. 0.0) GO TO 300
      GO TO 320
C     NORMALIZE SUM FOR SIMILARITY VALUE
400   CONTINUE
      IMAX=NTARG
      IF (NT .GT. IMAX) IMAX=NT
      XMAX=IMAX
      SIMVAL=SUM/(0.5*(XMAX*XMAX+XMAX))
      RETURN
      END
```

APPENDIX B

Table B-1
Categories and Classifications for each of Twenty Free-Response Items

Item No.	Stem	Category 1	2	3	4	5	6
1	TOLERABLE	bearable	*(no response)*	acceptable okay	patient understand	standable withstand	*(other)*
2	ALLEGIANCE	loyalty	*(no response)* pledge	support alliance	faithfulness	patriotism	honor *(other)*
3	CATASTROPHE	disaster	*(no response)* terrible	accident tragedy	crisis mess chaos *(other)*		
4	DIMINISH	lessen decrease shrink	fade reduce	end disappear smaller	*(other)*		
5	IMMACULATE	clean spotless	*(no response)* huge	perfect	pure holy	neat	*(other)*
6	CHRONIC	recurring habitual	*(no response)* serious	constant always	lasting persistent	*(other)*	
7	HOMAGE	respect honor	*(no response)*	tribute allegiance	praise worship adoration	*(other)*	
8	FLOG	whip beat lash spank flagellate	*(no response)* mistake	punish *(other)*			
9	ABHOR	hate detest dislike shun	*(no response)* stick	fear hide *(other)*			
10	IMPEDE	interfere hinder delay	*(no response)*	stop	block obstruct prevent	*(other)*	
11	REPRIMAND	scold admonish reprove	*(no response)* demand	punish discipline correct	*(other)*		
12	ADAGE	saying proverb	*(no response)* addition	story cliche phrase tale	*(other)*		
13	ACCLAIM	praise	*(no response)*	fame recognition	announce pronounce honor state	*(other)*	
14	QUALM	doubt misgiving reservation	*(no response)*	fight argument	fear worry	*(other)*	
15	ORB	sphere ball globe	*(no response)* eye path	circle round	*(other)*		
16	ALLOT	allocate assign	*(no response)*	distribute divide ration	give	allow	*(other)*
17	ACKNOWLEDGE	respond answer	*(no response)* accept	recognize notice	understand know	*(other)*	
18	MOLLIFY	pacify calm	*(no response)* change	soothe comfort quiet	subdue *(other)*		
19	SEDATE	calm quiet peaceful	*(no response)*	drug tranquilize	sleep relax	*(other)*	
20	PECUNIARY	monetary financial	*(no response)* small picky	peculiar strange different	*(other)*		

Table B-2
Categories and Classifications for each of Twenty Multiple-Choice Items

Item No.	Stem	Category 1	2	3	4	5	6
1	TOLERABLE	bearable	free flexible open-minded inferior *(no response)*				
2	ALLEGIANCE	loyalty	reading legibility protection fighting unit *(no response)*				
3	CATASTROPHE	calamity	celebration charity termination prophecy *(no response)*				
4	DIMINISH	lessen	flatten default undermine finish *(no response)*				
5	IMMACULATE	spotless	fashionable distinguished tardy powerless *(no response)*				
6	CHRONIC	constant	cowardly recorded	weak grouchy *(no response)*			
7	HOMAGE	reverence	abode	baseness food manhood *(no response)*			
8	FLOG	beat	stun	tread bother soak	*(no response)*		
9	ABHOR	detest	frighten accept urge release	*(no response)*			
10	IMPEDE	obstruct	summon	betray go by foot interrogate *(no response)*			
11	REPRIMAND	rebuke	refer to higher authority	recall by contrary order	demand repeatedly send back *(no response)*		
12	ADAGE	proverb	later years	custom	mental weakness normal condition	*(no response)*	
13	ACCLAIM	applaud	flaunt	indemnify	elect	denounce *(no response)*	
14	QUALM	misgiving	feeling of shame	state of rest	shudder	duty *(no response)*	
15	ORB	sphere	scepter	dome	track spur	*(no response)*	
16	ALLOT	assign	permit	increase spend seclude *(no response)*			
17	ACKNOWLEDGE	admit	understand	learn slowly examine with care approve of *(no response)*			
18	MOLLIFY	appease	accomodate	indemnify pamper	revise *(no response)*		
19	SEDATE	dignified	asleep	seated old-fashioned frail *(no response)*			
20	PECUNIARY	monetary	miserly	destitute	frequent	unusual	*(no response)*

Table B-3
Test Information Values for 19-Item
Free-Response and Multiple-Choice Tests

Theta	Free Response	Multiple Choice
-3.00	3.591	3.977
-2.75	4.637	4.828
-2.50	5.843	5.771
-2.25	6.995	6.735
-2.00	7.785	7.580
-1.75	8.073	8.151
-1.50	8.039	8.342
-1.25	7.926	8.127
-1.00	7.776	7.552
-.75	7.497	6.723
-.50	7.056	5.772
-.25	6.520	4.816
0	5.948	3.928
.25	5.344	3.151
.50	4.718	2.504
.75	4.108	1.986
1.00	3.556	1.583
1.25	3.081	1.274
1.50	2.681	1.039
1.75	2.346	.858
2.00	2.063	.718
2.25	1.819	.607
2.50	1.607	.516
2.75	1.420	.441
3.00	1.254	.376

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